Applications

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Optimizing the channel resource usage for sensor data sharing with V2X communications

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Abstract: Sensor data sharing in V2X communication enables vehicles to exchange locally perceived sensor data with each other to increase their environmental awareness. It relies on the periodic exchange of selected, safety-relevant objects. Object selection is used to reduce channel resource usage. Additionally, vehicles use congestion control mechanisms to avoid overloading the channel. Currently, both object selection and congestion control mechanisms operate independently. We study a congestion-aware object filtering approach combining both and improving the performance of sensor data sharing.

Keywords: collective perception; data congestion; V2X; vehicular communications.

Zusammenfassung: Die Übertragung von Sensordaten mit V2X-Kommunikation ermöglicht Fahrzeugen, lokale Umgebungsinformationen auszutauschen, um die Wahrnehmungsreichweite zu erhöhen. Der Sensordatenaustausch basiert auf der periodischen Übertragung sicherheitsrelevanter Objekte. Dabei wird die Anzahl der Objekte reduziert, um die Datenlast zu verringern. Zusätzlich steuern Mechanismen die Datenlast um eine Überlast zu vermeiden. Bisher arbeiten die Objektauswahl und die Datenüberlaststeuerung unabhängig voneinander. Wir untersuchen einen kombinierten Ansatz zur Objektfilterung, der die Performanz des Sensordatenaustauschs verbessert.

Schlagwörter: kooperative Wahrnehmung; Datenstau; V2X; Fahrzeugkommunikation.

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1 Introduction

In Europe, Vehicle-2-Everything (V2X) communication is at an early stage of deployment and is reaching the mass market. This first generation of V2X communication primarily supports applications for driver information and warnings. It relies on the exchange of messages over short-range communications with different message types, each serving a different purpose. The majority of data traffic consists of repetitively sent status messages by each vehicle to inform about its status and movements. They are transmitted in the 5.9 GHz spectrum, which is allocated for traffic safety and efficiency applications in Europe. The generated data traffic from all vehicles shares the limited capacity of the allocated spectrum, whereas mechanisms for congestion control ensure that the network is not overloaded. The European Telecommunications Standards Institute (ETSI) is one of the organizations that develop standards for message exchange in Cooperative Intelligent Transport Systems (C-ITS) using V2X communications.

The next generation of V2X communication is currently the subject of research, development, and standardization efforts. One of the main extensions will be the support of sensor data sharing among vehicles, referred to as "Collective Perception" in standardization. Collective Perception (CP) helps in particular automated vehicles to increase their environmental awareness by exchanging their perceived surroundings. It enables functions for the perception and tracking of objects, interpretation of traffic situations, and trajectory planning. Instead of sharing raw and bandwidth-intense sensor data such as video streams, CP relies on the exchange of pre-processed sensor data as lists of detected and classified objects in periodically sent messages.

CP can use extensive channel resources when the number of objects carried in V2X messages is high, which increases the probability of collisions in the medium access. To prevent channel overloading, objects are selected for transmission based on their dynamics. In addition, the congestion control mechanisms may discard messages based on their priority and available channel access. While both mechanisms support the goal of controlling the usage of channel resources, they are not cooperating. Including objects for transmission should depend on the available resources and relevant object characteristics, which is not the case yet.

This paper studies the optimization of a congestion-aware filtering method to adapt the number of included objects to the available transmission resources determined by the V2X congestion control. We quantitatively assess the performance of the new sensor sharing protocol with the studied filtering approach and find its parameter that maximizes a score metric combining channel usage, information redundancy, and environmental awareness. The evaluation is performed with a coupled network and mobility simulator that accurately models both the V2X communication protocols as well as the vehicle density and their movement for a representative mid-size German city.

The sensor data sharing approach defined by ETSI as CP was studied in other research publications. Initial work on the potential, concept, and prototype implementations of CP can be found in refs. [1, 2]. Message generation rules were addressed by refs. [3–5]. Congestion-aware filtering in collective perception messages was assessed in refs. [6, 7]. In comparison to the two previous works, we investigate the congestion-aware filtering algorithm using new metrics developed in ref. [8] and optimize its performance by adjusting its parameters.

The remainder of the paper is structured as follows: Section 2 gives an overview of sensor data sharing based on the current specifications in standards and introduces the enhancements for congestion-aware filtering. Section 3 presents the simulation environment and the evaluation results, followed by the conclusion in Section 4.

2 Collective perception

The recent R & D efforts on sensor data sharing have led to initial draft standards. As an intermediate result, ETSI has completed the study item TR 103 562 [9] for CP, which is considered the baseline for the enhancements presented in this paper. Figure 1a shows a flowchart of the sender-side CP process as defined in ref. [9]. Note that the step marked with a dashed box is not part of the baseline solution; it represents an extension and will be presented later. Following Figure 1a, at first, the sensors mounted on a vehicle gather the objects perceived in their surroundings. All objects are collected to obtain a fused list of objects.

The CP Service (CPS) is responsible for the generation of Collective Perception Messages (CPMs); a CPM cannot be sent more than once every 100 ms and less than once every second, i.e., with a rate between 1 and 10 CPM/s [9]. Upon generation of a CPM, the CPS passes the fused object list and applies Perceived Object Container (POC) inclusion rules. These rules reduce the number of objects to be transmitted based on their dynamics and freshness. Concretely, this filtering step operates such that if an object was included in

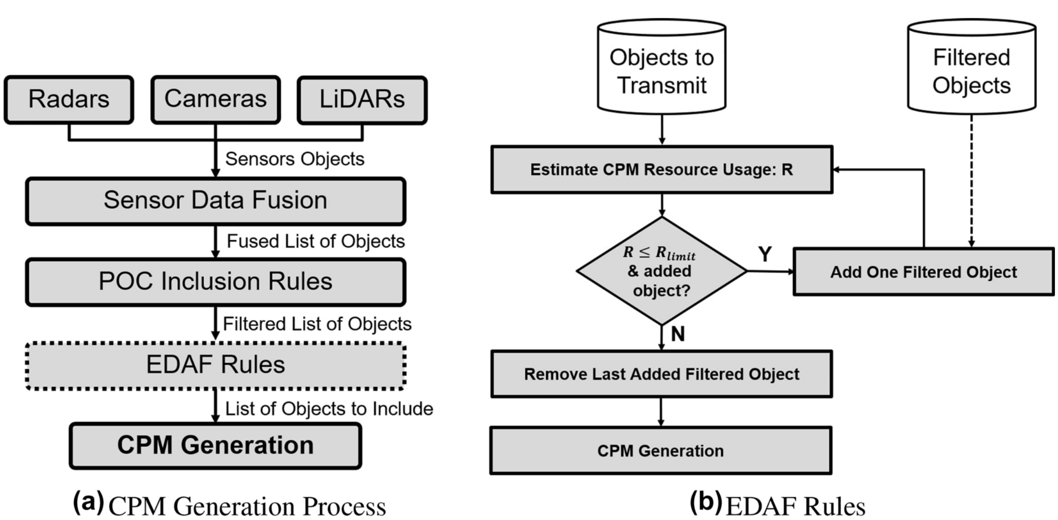

Figure 1: CPM generation process and EDAF rules.

a CPM (i) during the last second or (ii) its position, ground speed, or orientation did not change more than 4 m, 0.5 m/s, and 4°, respectively, then the object is not included in the generated CPM. The POC is a container in the CPM that carries the position, speed, and heading for every object that is selected for transmission. Following [9], after finishing the object filtering process, a CPM is generated if there is at least one object for transmission or if the last CPM generated with sensor information data was longer than 1 s ago. In this paper, we add an extra step to the CPM sending process (dashed box in Figure 1a): The "Enhanced DCC Aware" (EDAF) rules are executed after the inclusion rules and before the CPM generation. In our previous work [5–8], we found that object filtering should not be applied in a constant manner but be adapted to the currently available resources for CP. These rules for congestion awareness were initially proposed in ref. [6] and extended in ref. [7]. We note that the approach is in line with the current draft specifications for CP in ETSI.

Figure 1b illustrates the process pursued by the EDAF rules. After the POC inclusion rules, two sets of objects exist: one with the selected objects for transmission and the other with the filtered objects. The objective of the EDAF rules is to allow filtered objects to be included into the CPM as long as resources for the CPS are available. The steps for the EDAF rules are:

1. Evaluate the ratio of the available resource, R, that the CPM would use by including the objects selected for transmission and the corresponding lower layer headers. $R = \frac{T_{\text{on}}}{\delta}$ where T_{on} is the transmission time of the generated packet containing the CPM and δ the allocated duty cycle on the channel computed by the adaptive congestion control mechanism defined in ref. [10].
2. If R is lower than a fixed threshold R_{limit}, then a randomly chosen filtered object, if any, is added to the list of objects to transmit. Then, step 1 is repeated.
3. If R is higher or equal then R_{limit}, the last of the added filtered object is removed, if any, and the CPM is generated with the new object list.

The present paper aims to find a value for R_{limit} that optimizes the resource usage of the CPS. For assessment, we use an abstract metric named score, which combines channel load, environmental awareness, and information redundancy. In our previous studies [7], R_{limit} was fixed to 0.1, which corresponds to 10% of the available channel resources and allows to send 10 CPMs per second. However, based on the information redundancy and the score metrics developed in [8], we will show that another setting for R_{limit} is preferable.

3 Performance evaluation

3.1 Simulation environment

To analyze the impact of the R_{limit} on the EDAF rules and CPS, we rely on the well-known Artery[1] framework, a V2X simulator based on Vanetza, INET, and OMNeT++. Artery is coupled with SUMO for the modeling of vehicle traffic and mobility. We used the SUMO scenario InTAS [11] with a snapshot of road traffic at 9:15 a.m. which corresponds to a rush hour for our simulations. Each simulation run has a duration of 13 s with 10 s of warmup and is repeated twice with different seeds.

V2X services and CPM format: Each V2X capable vehicle in the simulations exchanges CAMs and CPMs. Both CA and CP services are enabled. The CA service operates on the Control Channel (CCH) and the CPS on the Service Channel 1 (SCH1) of the 5.9 GHz frequency band. A vehicle can receive and send messages simultaneously on both channels without adjacent channel interference. The CAM relies on the ETSI EN 302 637-2 [12] and the CPM on ref. [9]. Specifically, the CPM consists of the following containers: a message header indicating the message type and the station id, the management and station data containers containing information about the sender such as position, heading, and velocity, Sensor Information Containers (SICs), and 0 to 256 POCs. For the congestion control mechanism, we use the adaptive approach of ref. [10] with the dual-alpha approach as proposed in ref. [13].

Vehicle equipment and object detection: It is assumed that with the increasing deployment of C-ITS, the ratio of vehicles equipped with V2X technologies will grow over time. The larger the ratio, the higher gets the generated data load on the channel. For our study, we varied the V2X equipment penetration rate, i.e., Market Penetration Rate (MPR), and used the values MPR = 10%, 20%, …, 90%, and 100%.

For object detection, the vehicles have local sensors mounted on them and we used a sensor configuration inspired by Tesla brand vehicles.[2] The result is a radar facing the front of the vehicle with a 160 m range and 35° Field of View (FoV). A second radar is mounted with an FoV of 325° and 80 m range to cover the back of the vehicle. A radar detects an object if one of its four corners is its direct line of sight. Other vehicles or buildings obstruct the line of sight of the radars. When an object is detected, all its attributes

1 http://artery.v2x-research.eu. Last accessed: 23 Nov. 2022.
2 https://www.tesla.com/autopilot. Last accessed: 23 Nov. 2022.

are perfectly known, i.e., they are no inaccuracies in the measurements of the radars.

3.2 Metrics

We assess the performance of the proposed Collective Perception approaches with the following metrics:

- **Channel Busy Ratio (CBR)**: Time-dependent value between zero and one representing the fraction of time that a single radio channel is busy with transmissions;
- **Environmental Awareness Ratio (EAR)**: The ratio of known objects by a vehicle on the actual number of objects in an area delimited by a circle with a radius of 500 m centered at the vehicle;
- **Redundancy Level (RL)**: The ratio of the number of updates received about an object divided by the number of updates that the object would have sent if it would have generated CAMs following the CAM generation rules [12] during the last second;
- **Score**: The score is a single value obtained by combining the obtained median of the CBR, EAR, and the Redundancy Valuation (RV). The score is computed following Eq. (1). We use the RV as defined by Eq. (2) instead of the RL to enable controlling the value of information redundancy for an object. With the set parameters, $RV \sim 1$ when $RL \geq 3$. More information on this metric in ref. [8].

$$\text{Score} = (1 - CBR) \times EAR \times RV \tag{1}$$

$$RV = ae^{-be^{-cRL}}, \text{ with } a = 1, b = 7, c = 2.31337 \tag{2}$$

3.3 Results

In this section, we present the main outlines of the obtained results as shown in Figures 2–4. Two vital observations for the rest of the analysis. First, the No EDAF rule behaves the same as EDAF $R_{\text{limit}} = 0.01$. We'll then only refer to the No EDAF rule. Second, the obtained EAR does not depend on the application of the EDAF rule. At MPR = 0.65, the EAR is at around 0.66, then increases up to 0.92 at MPR = 0.3 to reach close to 1.00 at MPR = 0.7. Figure 2 shows the score obtained for the different configurations of the EDAF rules. The results can be divided into three categories: MPR < 0.3, MPR = 0.3, and MPR ≥ 0.3.

At **MPR < 0.3**, the difference between the application of the EDAF rules is the most significant. The higher R_{limit} is, the better the score is. As shown in Figure 3, the channel usage is low and there is only a little difference in channel usage. This shows that exploiting available channel resources can help improve CPS performance. The score difference is influenced mostly by the RL as indicated in Figure 4. It should be noted that the RL is higher because vehicles send object updates more often, not because there are more sources of information for an object. At **MPR = 0.3**, the score for each of the EDAF rules reaches its maximum or is close to it. The score of all the configurations is around 0.8. While the difference in terms of used CBR becomes more significant, the RL increases almost linearly. EDAF rules with $R_{\text{limit}} \geq 0.03$ have an RL such that the redundancy valuation saturates at around 1 (see Eq. (2)). At **MPR > 0.3**, the higher the MPR is, the lower the score is. The reason is that the information redundancy and CBR as shown in Figures 3 and 4 keep increasing while the valuation of the information redundancy stays the same. In other words, Collective Perception uses channel resources more than necessary. Importantly, only the EDAF rules with $R_{\text{limit}} \geq 0.05$ perform worse than the No EDAF rules. The selection of the parameter R_{limit} should not result in the deterioration of Collective Perception performance. Therefore, the value $R_{\text{limit}} = 0.03$ seems

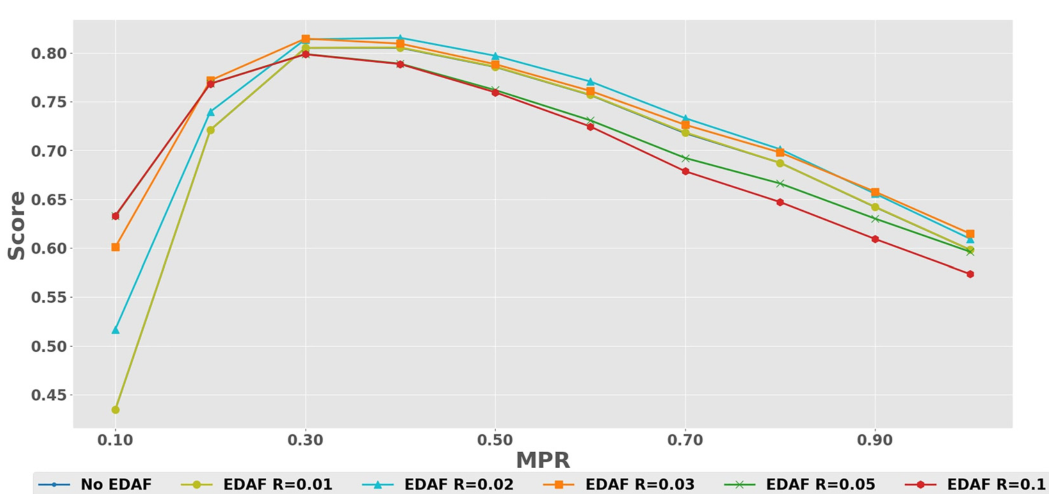

Figure 2: Scores obtained for the different values of R_{limit} (marked as R in the figure legend).

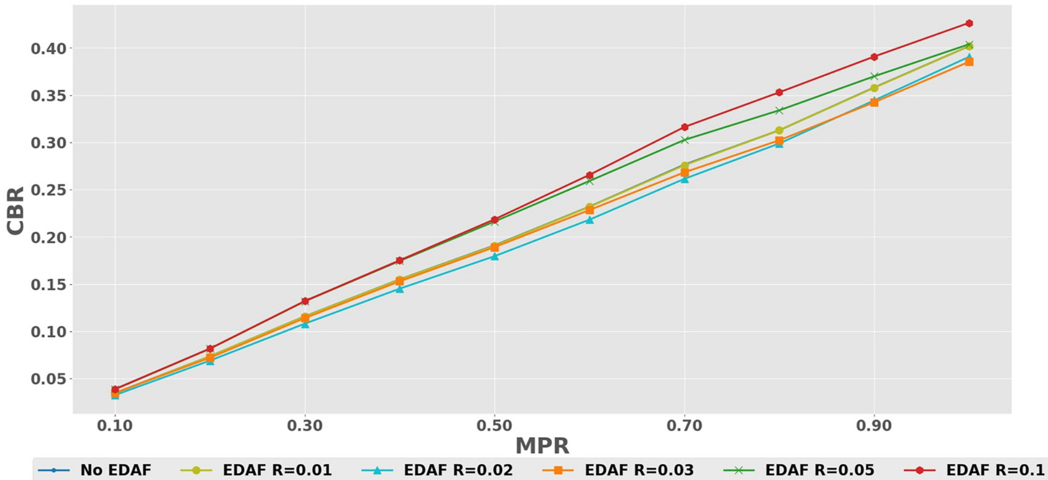

Figure 3: CBR obtained for the different values of R_{limit} (marked as R in the figure legend).

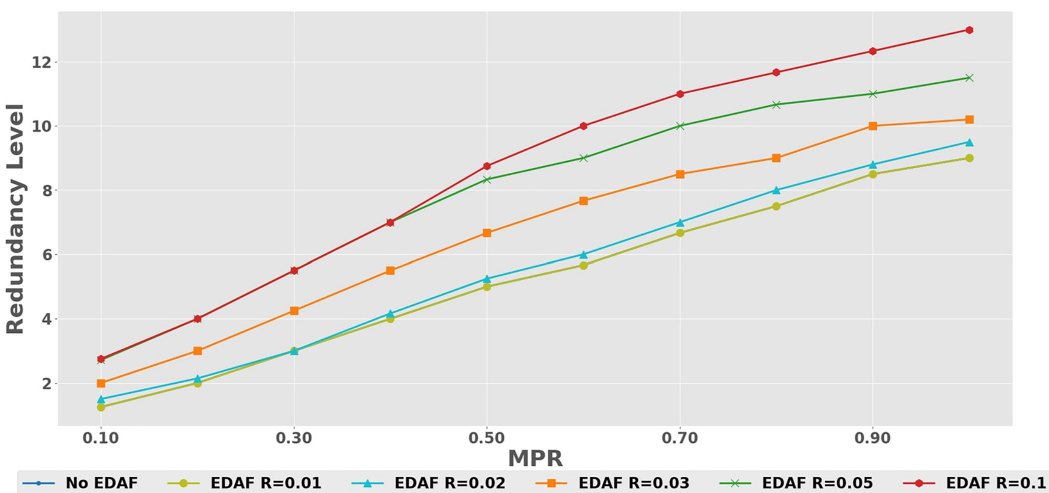

Figure 4: RL obtained for the different values of R_{limit} (marked as R in the figure legend).

the most profitable one as it increases significantly the score at low MPRs while maintaining slightly better performance at higher MPRs than the No EDAF rule.

4 Conclusion and further work

Sensor data sharing is a key component for the next generation of V2X communications. We showed in this paper that the current object inclusion rules specified by ETSI can be improved following a generic score metric taking into account the channel load, information redundancy, and environmental awareness. We performed a parameter study to enable initially filtered objects to still be transmitted and allow for better channel usage, especially at the early stage of V2X system deployment. The results indicate that the proposed rules for congestion-aware filtering EDAF when correctly configured can achieve the desired goal. Further work includes the combination of information redundancy mitigation techniques with the EDAF rules to address the problem of information redundancy.

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Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

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